anced Measurements Optical Ra (AMOR)

Ladar Center of Excellence

U.S. Army Space & Missile Defense Command
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INTRODUCTION

The Advanced Measurements Optical Range (AMOR) is a compact, indoor optical test range located at Redstone Arsenal (Huntsville), Alabama. AMOR is designed to allow measurements of far-field and near-field optical signatures of large-scale targets filling up to 2 meters of field.

AMOR is a U.S. Army Space and Missile Defense Command (USASMDC) facility, and is a component of the system of Ground Test Facilities of the inter-service Missile Defense Agency (MDA). The facility was formerly known as the Army Missile Optical Range.

The measurements system consists of five major subsystems:

1) The optical system
2) The target mount system (included here are the beam profiling system and the facility light shielding)
3) The laser transmitters
4) The optical detection and RF signal processing systems
5) The data recording and processing systems

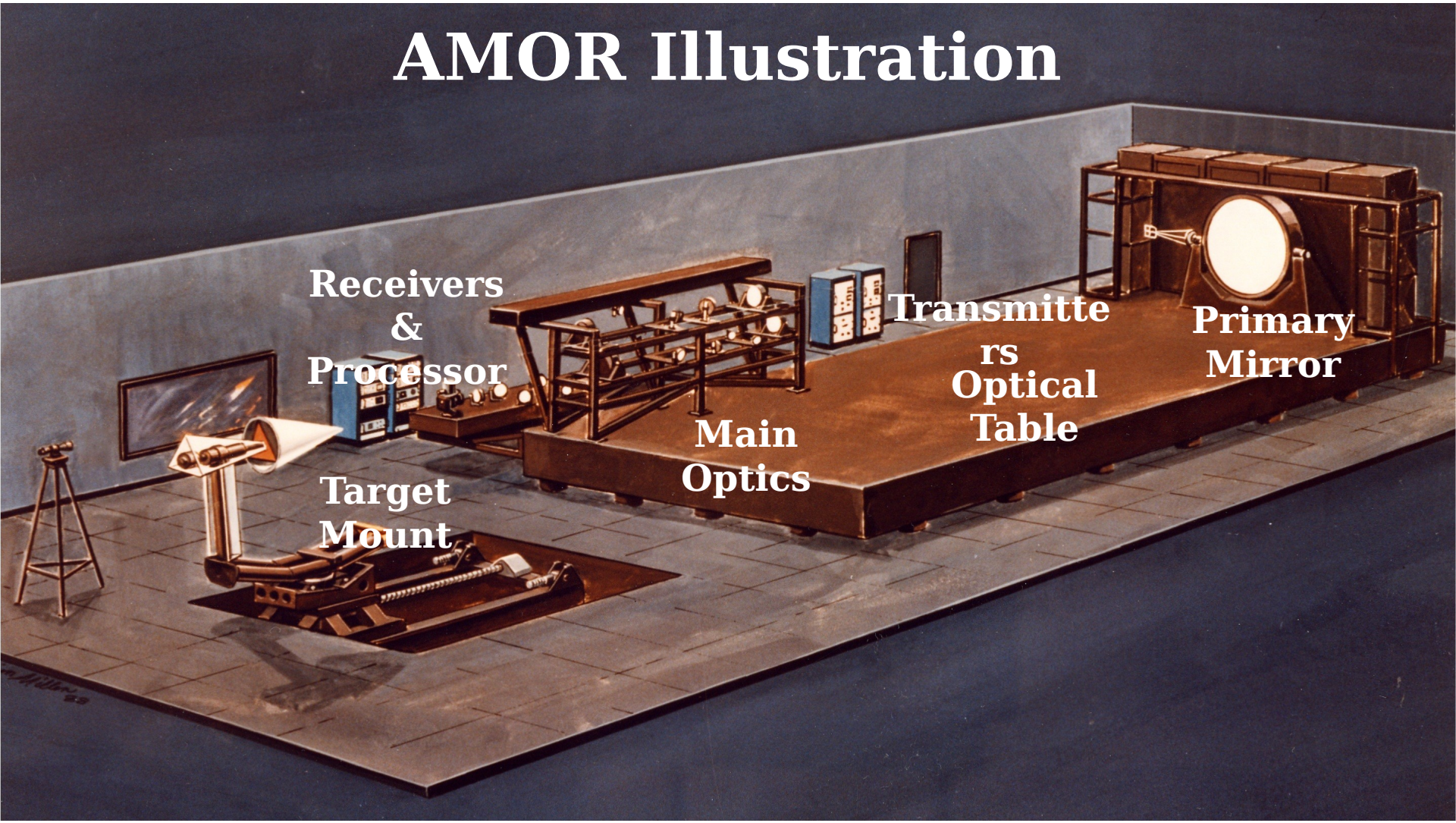
The *AMOR Illustration* on the facing page gives an overview of the AMOR facility. The 2-meter aperture primary mirror, which is part of both the illumination and receiving optical systems, and the target mount, are on the opposite ends of the facility. The other main telescope mirrors are on the optical bench superstructure on the side of the main optical table. The main optical table is pneumatically vibration isolated. The laser transmitters and optical detectors are on smaller optical tables attached to the edge of the main optical table, and the laser controllers, RF processor, and data recording/processing system equipment racks are seen on the far wall.

The subsystems vary somewhat depending on the measurement wavelength. The optical receivers described here form a virtual receiver aperture at infinity, or a long range, and collect signals with a single element optical detector. Transmitters, receivers, and data processors are available to make range-Doppler resolved cross-section measurements at the 1.064 μm and 10.6 μm wavelengths, and total cross-section measurements at 532 nm.

Besides allowing target signature measurements with in-house transceivers, the AMOR facility serves as a host test-bed for the evaluation of ladar transmitters, receivers, and signal processors, which may be substituted for any of the standard AMOR subsystems or components.

A zoom range simulation optical system is available which allows focal-plane-array sensors

AMOR Illustration



THE MAIN OPTICS

The main optics consist of a pair of telescopes; one acts as an 82:1 laser beam expander for collimated flood illumination of the target, and the other collects the light scattered from the target through a 110:1 telescope and optically constructs a far-field or near-field aperture. The transmit and receive telescopes share a common 2-meter diameter primary mirror. The target illumination and the rays received from the target are separated by a 1 milli-radian bi-static angle, which for most purposes (diffuse targets) can be considered to be mono-static. The *AMOR Illumination and Light Collection Concept* shows a simplified refractive representation of the AMOR main optical system.

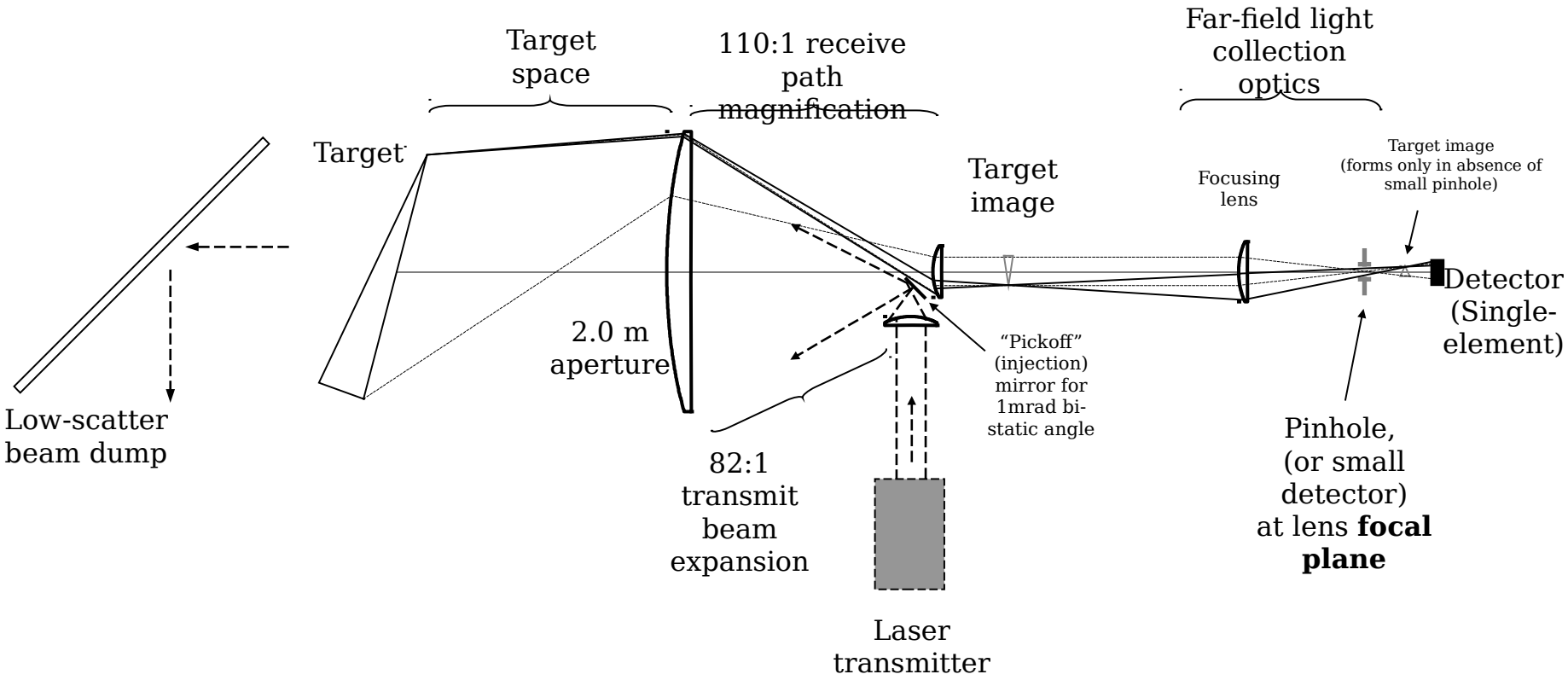
Note that the transmit and receive optics are not symmetric; the receive optics optically construct a far-field light collection aperture using a pinhole at a lens focal plane, while the transmit optics put the target in the near-field of the laser transmitter output aperture.

The two telescopes, with their shared spherical primary mirror, are each of a reflective, 4-mirror, off-axis design which produces no central obscuration. The *AMOR Receive Path Optics* shows a simplified illustration of the AMOR receive optical train with several flat fold and feed mirrors not shown. The final focusing lens and pinhole mentioned in the previous paragraph follow these reflective elements. The transmit and receive telescopes are identical except for the focal length of their parabolic quaternary mirrors. The aberrations resulting from the 6˚ off-axis spherical primary mirror are corrected by the hyperbolic secondary and tertiary mirror design. In the transmit path, since the rays are reversed with respect to the receive path, one could view the tertiary and secondary mirrors as "pre-aberrating" the beam in an inverse manner so that the aberrations of the primary mirror will cancel out the pre-aberrations. This can be seen by viewing the beam caustic at the focus between the secondary and primary mirrors in the transmit path; it appears as a large, comatic and otherwise smeared out spot (several centimeters in one dimension, several millimeters in the other dimension) rather than as a pinpoint focus.

Separate components are used for most of the transmit and receive optics in order to minimize diffuse backscatter of the transmit beam back into the receiver from elements common to the transmit and receive path. In a larger beam, there is less backscatter per solid angle into the receiver ($1/D^2$ relationship), so the 2-meter diameter primary mirror causes less backscatter than would any element in the smaller beam. Moreover, by limiting the spurious backscatter to a single component, it is limited to a single range (or single family of range ambiguities), which may be more easily discriminated against by the data processing system (by range gating).

A spherical primary mirror design was chosen not only because it is easier to manufacturer

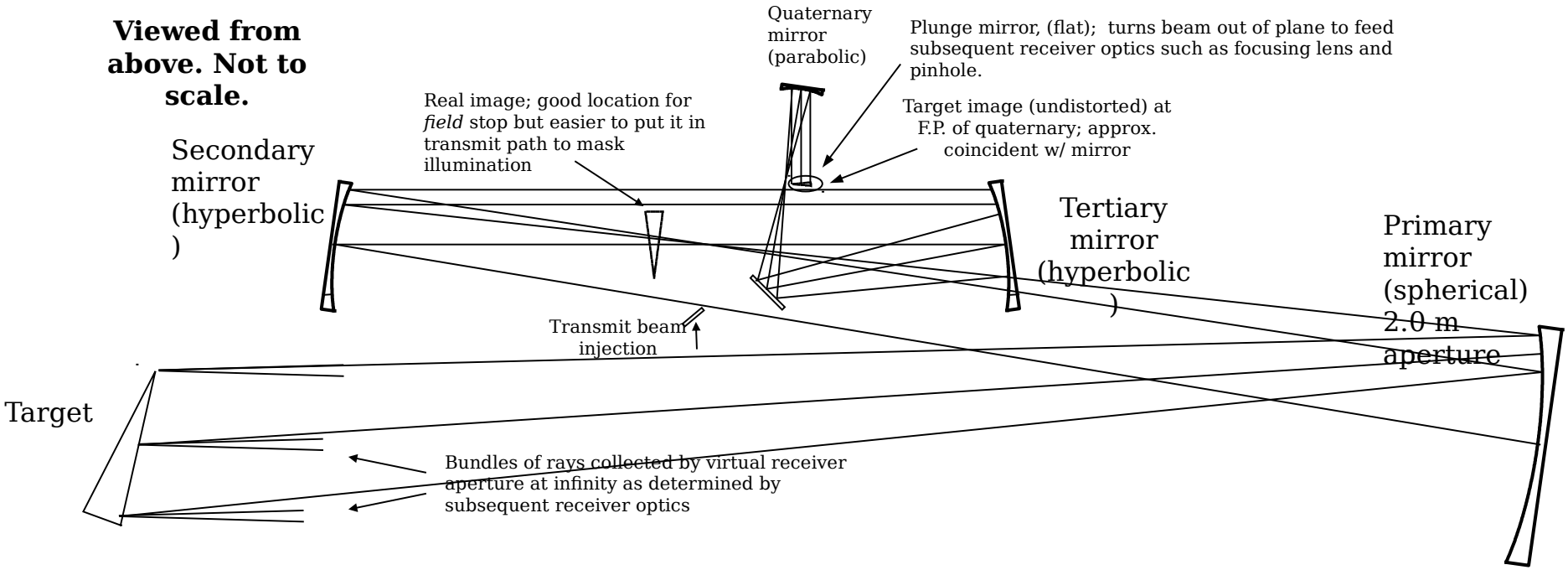
AMOR Illumination and Light Collection Concept



Actual AMOR reflective optical system is represented here as a pair of simple refractive telescopes

Note the wide separation between *focal planes* and the *image planes*.

AMOR Receive Path Optics

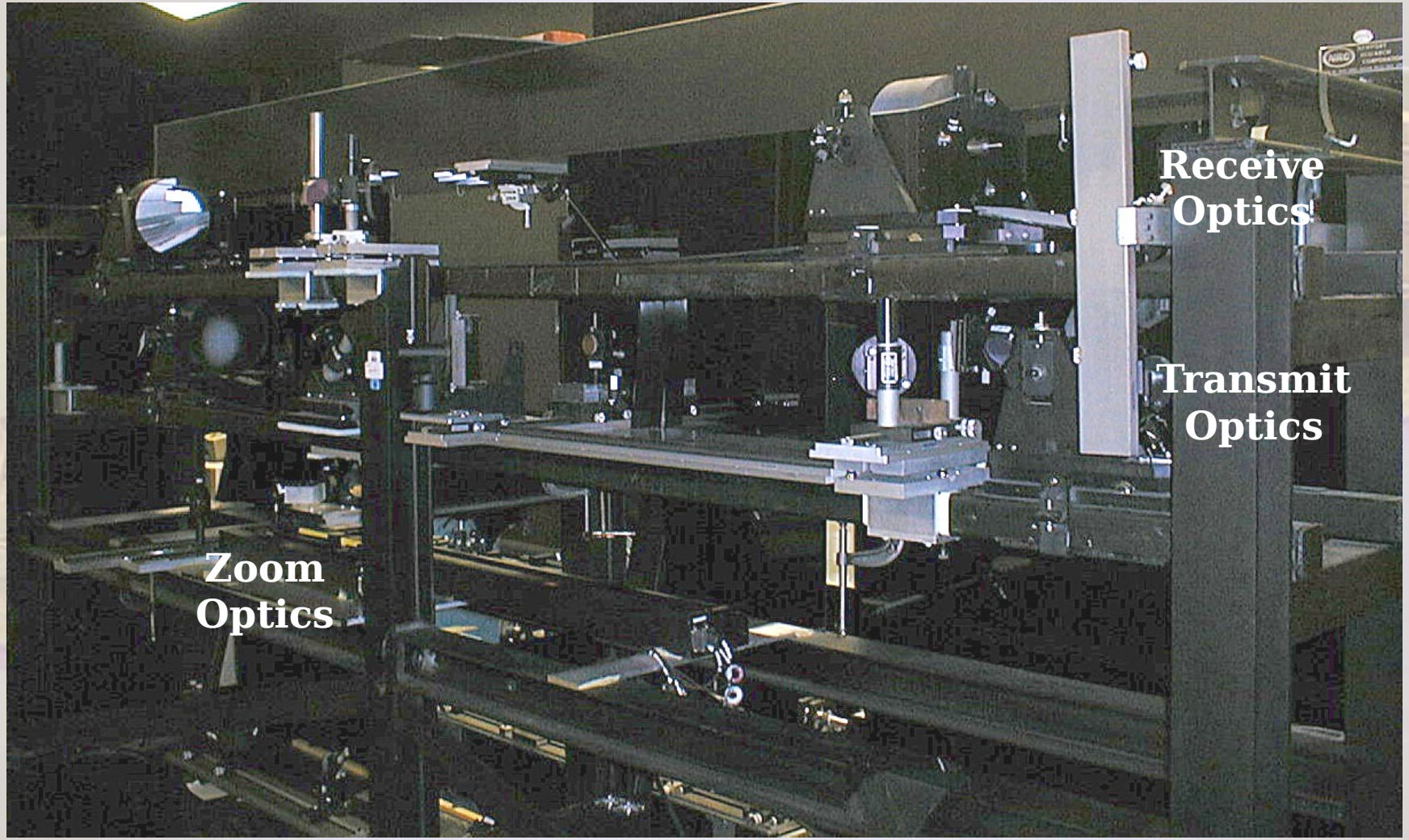

Viewed from above. Not to scale.
Secondary mirror (hyperbolic)
Quaternary mirror (parabolic)
Plunge mirror, (flat); turns beam out of plane to feed subsequent receiver optics such as focusing lens and pinhole.
Real image; good location for *field* stop but easier to put it in transmit path to mask illumination
Target image (undistorted) at F.P. of quaternary; approx. coincident w/ mirror
Tertiary mirror (hyperbolic)
Primary mirror (spherical) 2.0 m aperture
Transmit beam injection
Target
Bundles of rays collected by virtual receiver aperture at infinity as determined by subsequent receiver optics

• Collimated rays shown follow the centers of the ray bundles through the system

System axis coincides with hyperbolic and parabolic mirror axes (Secondary through Quaternary)

“Pickoff” mirror at Primary mirror focus is point of injection of transmit beam into common Primary mirror from separate Secondary through Quaternary transmit optics

AMOR Main Optics Bench



OPTICAL SYSTEM FEATURES

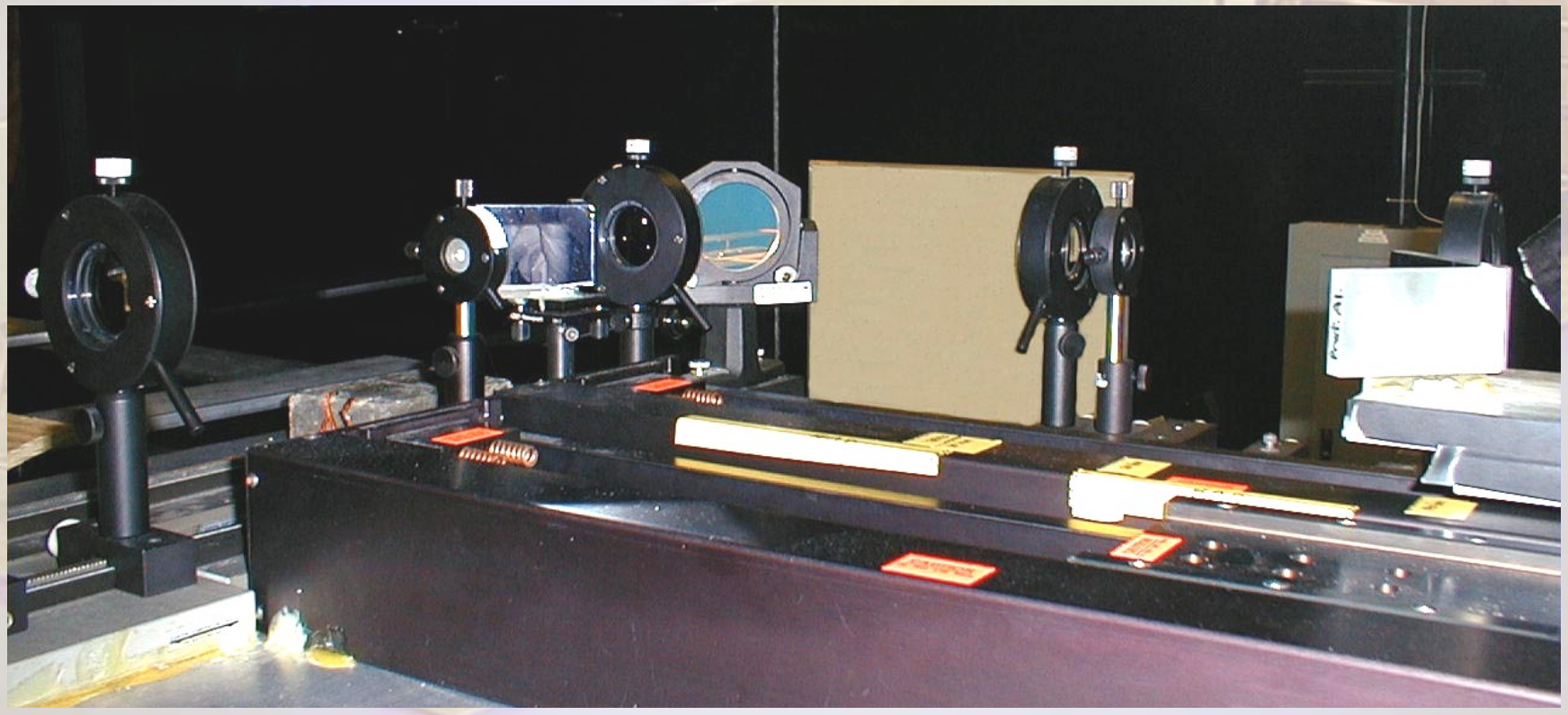
The transmit beam expander accepts a 25 mm diameter beam from the laser transmitter and expands it by a factor of 82 to a 2-meter diameter collimated beam to flood illuminate the target plane. The transmitter output beam is normally set to fill this beam expander so that the intensity rolls off by about 25% from the beam center to the beam expander edge, where it hits the hard aperture of the primary mirror. This degree of roll-off was chosen as a compromise between illumination uniformity and total power within the 2-meter field. Injecting a larger beam diameter into the transmit beam expander would result in a flatter profile, but more energy would be lost outside the 2-meter diameter primary mirror. This nearly uniform, collimated target illumination approximates common beam profiles at long ranges, and insures that the transmit beam characteristics minimally affect the measured target characteristics. The target illumination profile is not, however, the far-field profile of the transmitter laser being used, but is in fact the near-field profile.

Scattered light is collected from the target by the main 110:1 receive telescope. To produce a virtual far-field collection aperture, this telescope is followed by a focusing lens and a pinhole at the lens focus, as shown in the *AMOR Illumination and Light Collection Concept* drawing. The pinhole throughput is collected by a photo-detector, usually via a condensing lens. In some cases a small photo-detector is used in place of the pinhole. The focusing lens and detector follow all of the reflective optics shown in the *AMOR Receive Path Optics* diagram. Since the pinhole is located at the focal plane of the lens, rather than at the image plane, it acts as an aperture stop, i.e., its size does not affect what portion of the target is viewed, but instead determines how large a bundle of rays is collected. The rays collected from each point on the target are centered about a ray parallel to the system axis. As seen by the target, the pinhole (or detector) appears at infinity and has a small angular diameter (determined by the pinhole diameter and the final lens focal length); it thus acts as the simulated receiver aperture at infinity and collects a far-field signature. Since a single detector collects all of the light from this simulated receiver aperture, the measurements obtained are transversely unresolved.

For coherent (heterodyne) measurements, as are made with the 1.064 μm and 10.6 μm ladar transceivers at AMOR, the simulated receiver angular aperture is set to be approximately equal to a single speckle angular size as determined by the smallest speckle (wavelength divided by target diameter) that can be produced by a 2-meter diameter target. For incoherent (direct detection) measurements, as are made with the 532 nm ladar transceiver at AMOR, a much larger simulated receiver angular aperture is usually used to allow the collection of more light. The transverse speckle averaging thus produced improves the SNR for the incoherent measurements.

Additionally, a zoom range simulation optical system is available which allows focal-plane-

AMOR Zoom Range Simulation Optical System



TARGET MOUNT SYSTEM

The *AMOR Main Target Mount* provides full spin, wobble, and precession motion as well the aspect angle and translation position of the target. Rotational encoders continuously provide spin and precession angular position which is recorded along with the data. The target mount is translatable in range to allow for positioning of the target in particular range gates and for translation during data acquisition to produce Doppler shift. A linear position sensor provides axial target position information.

For target measurements without precession, the aspect angle of the target is set such that the illumination beam axis and the target symmetry axis (spin axis) form a horizontal plane. For precession motion, the illumination beam axis and the axis of precession form a horizontal plane.

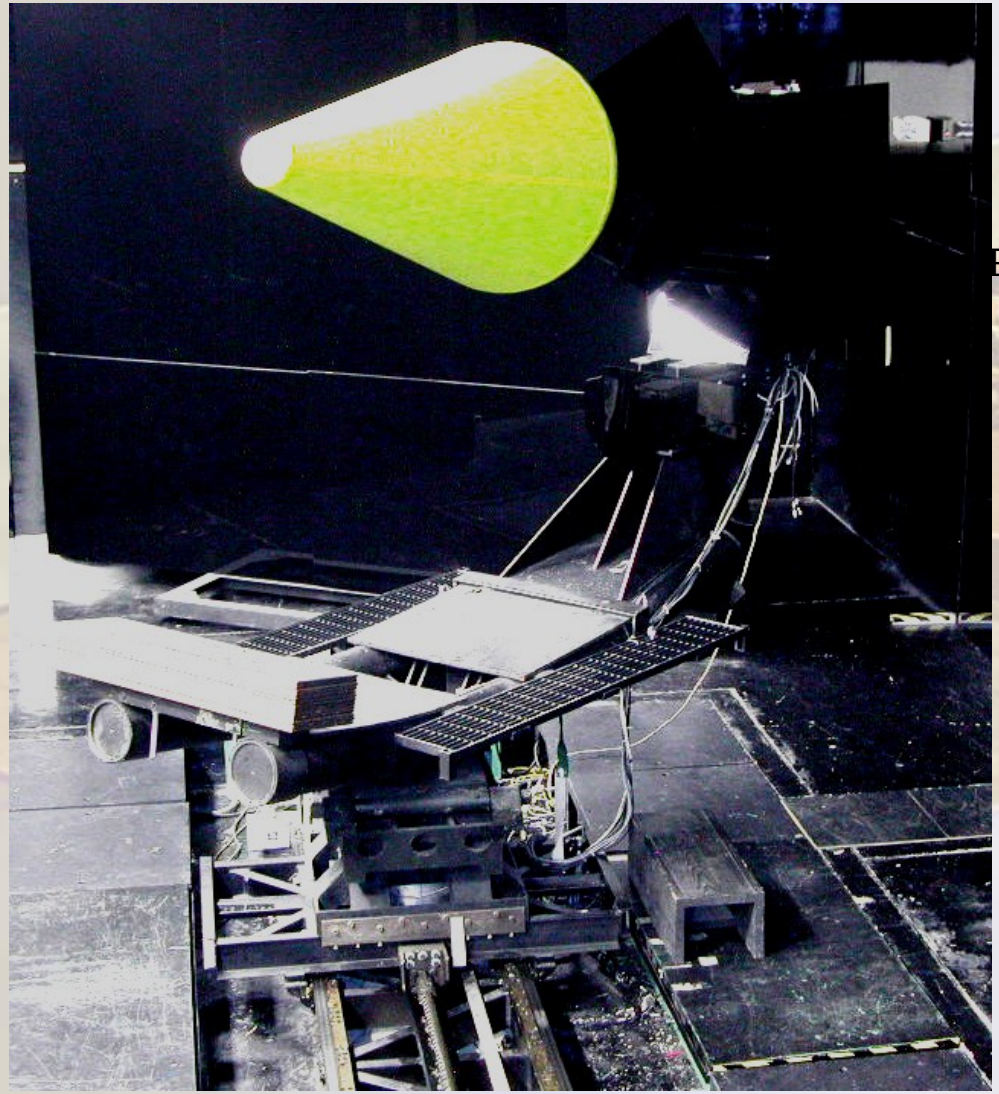
The main target mount can hold targets up to 275 kg. The spin rate is continuously variable between 0 and 3 Hz. The available precession (coning half-angle) angle and rate depend on the mass of the target. For example, with a coning half-angle of ≤ 10°, a target up to 275 kg can be handled at a precession rate of 15°/sec. Alternatively, with a coning half-angle of 35°, the target handling capacity is reduced to 55 kg at a precession rate of 15°/sec. The target translation velocity is variable between 0 and 0.5 m/sec while the target-to-beam aspect angle is continuously variable between 0° and 90°. Auxiliary target mounts are also available to hold additional target objects simultaneous to the use of the main target mount. These auxiliary mounts can handle less weight and have fewer degrees of freedom than the main target mount.

The main target mount is also used to hold calibration objects. The data acquisition system accepts the output from the target mount position sensor and can register receiver data to the target mount position to allow gate range response curves to be generated.

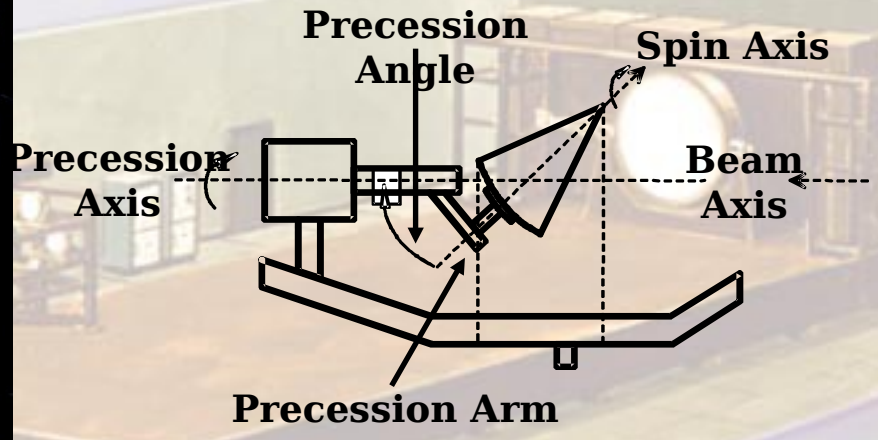
To minimize spurious scatter into the receiver, low scatter shielding is appropriately placed behind the target mount, on the target mount, and at other appropriate locations in the room. Flat plates of “shiny” black, cast acrylic are used as the shielding material. This material has a very low diffuse scatter coefficient, and the specular component of scatter (about 4%) can be easily directed in harmless directions to be absorbed by further acrylic shields and beam dump baffle structures.

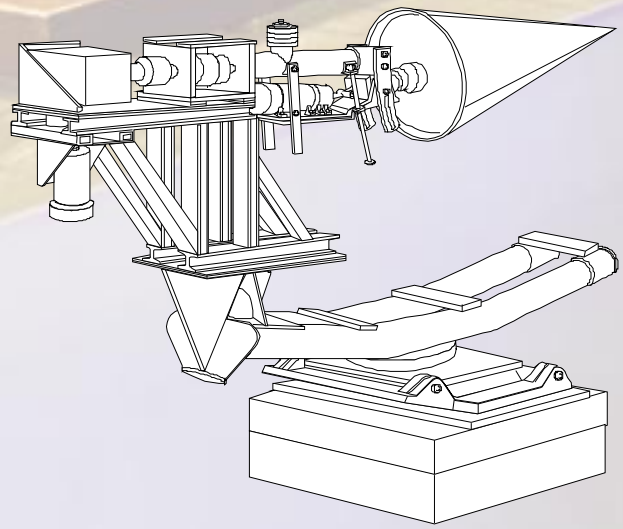
Pyramidal shield structures have been found to be particularly useful on the rotational portions of the target mount. Large shield plates are typically oriented at a large enough angle to the beam that diffuse scatter from them is extended though several range gates, rather then being concentrated in a single gate, as it would be if the plates were nearly normal to the beam. Exactly normal orientations are avoided due to the large glint which would occur from the 4% specular

AMOR Main Target Mount



Spin and Precession Motions





"Secure the High Ground"

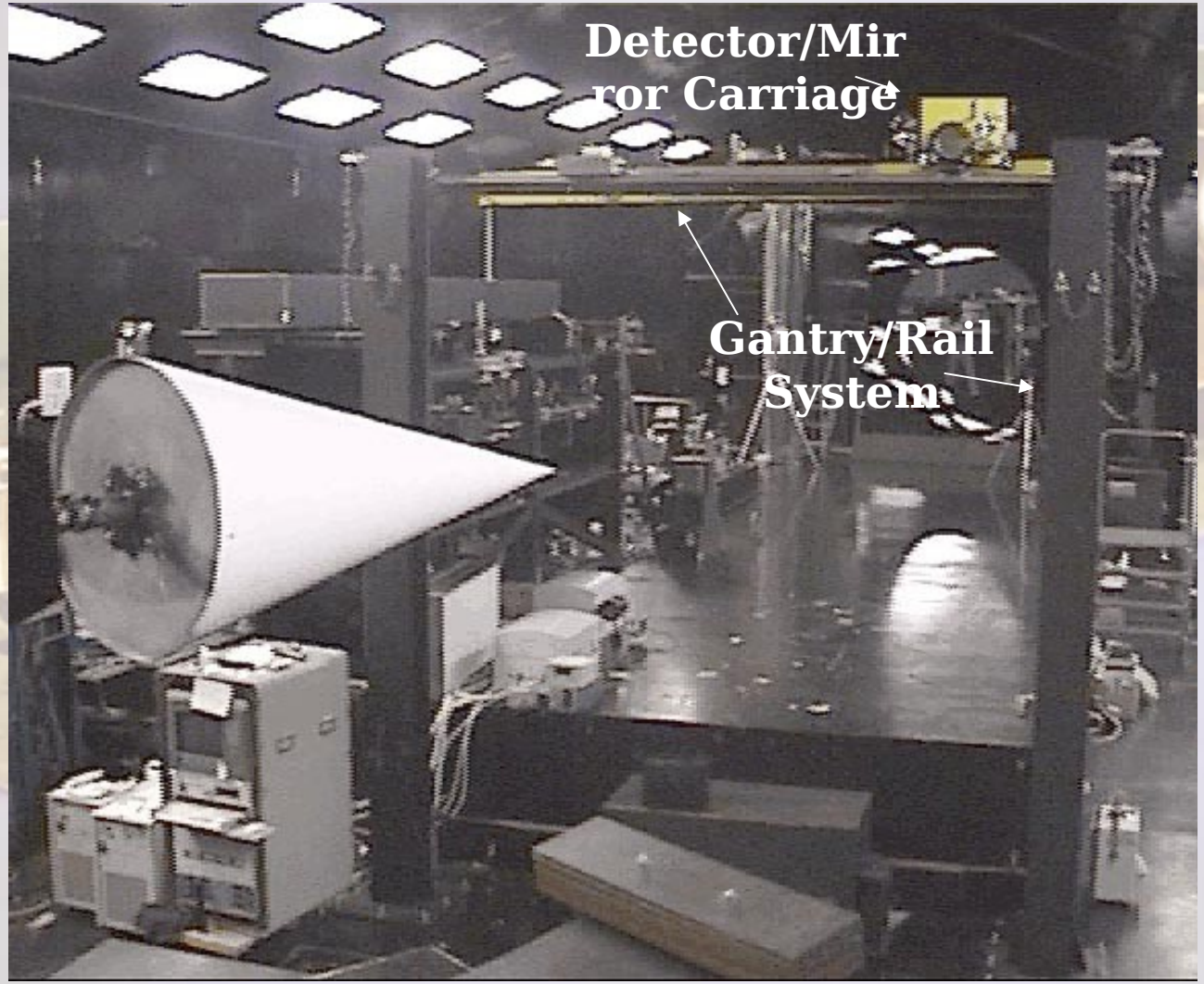
BEAM SCANNING SYSTEM

The AMOR facility has a transverse scanning system that allows a detector to be moved horizontally and vertically across the 2-meter target plane. The scanner's vertical and horizontal translators have position sensors, and a computer data acquisition system registers the scanned detector output to the scanner position coordinates to produce a beam profile. This allows a beam profile to be produced to ensure that the target illumination is adequately uniform, and is used as an aid in transmit path alignment.

Similarly, a spherical mirror is scanned, which reflects light back into the receiver, to allow a round-trip system response profile to be produced. From the round-trip profile and the transmit profile, the accuracy of the receive path alignment can be inferred.

The *Beam Scanning Gantry and Rail System* can be seen in the picture which shows a view of the AMOR facility looking from the target region toward the primary mirror.

AMOR Beam Scanning Gantry and Rail System



LADAR TRANSMITTER SYSTEM - 10.6 µm

For 10.6 µm range-Doppler resolved measurements, a mode-locked, RF excited CO_2 Multi-Folded Laser (MFL) oscillator with a 3-meter resonator is used as the transmitter. The MFL laser oscillator design has 2.9 meters of 2 x 2 mm waveguide gain length folded into a ceramic plate of 6.0 x 6.75 cm approximate dimensions. The gain section of the oscillator is contained in the cylindrical housing shown in the *AMOR 10.6 µm Laser Transmitter* photograph with an acousto-optic modulator in the free space propagation section between the housing the end mirror.

The pulse duration is 1.35 ns, which allows the receiver system to micro-resolve the target in range. The mode-locked pulse repetition frequency (PRF) is 50 MHz, which produces a range ambiguity of 3 meters; this is the longest projected target length that can be viewed without overlap with itself, and is also the periodic range over which signal from clutter can overlap with that from a target. The mode-locked pulse train average power is 25 W. While the transmitter waveform is continuous duty, the data acquisition system typically acquires 1.024 ms records of data (50,000 mode-locked pulses) at a rate of 10 Hz, so the effective transmitter energy is 25 mJ with a 10 Hz PRF.

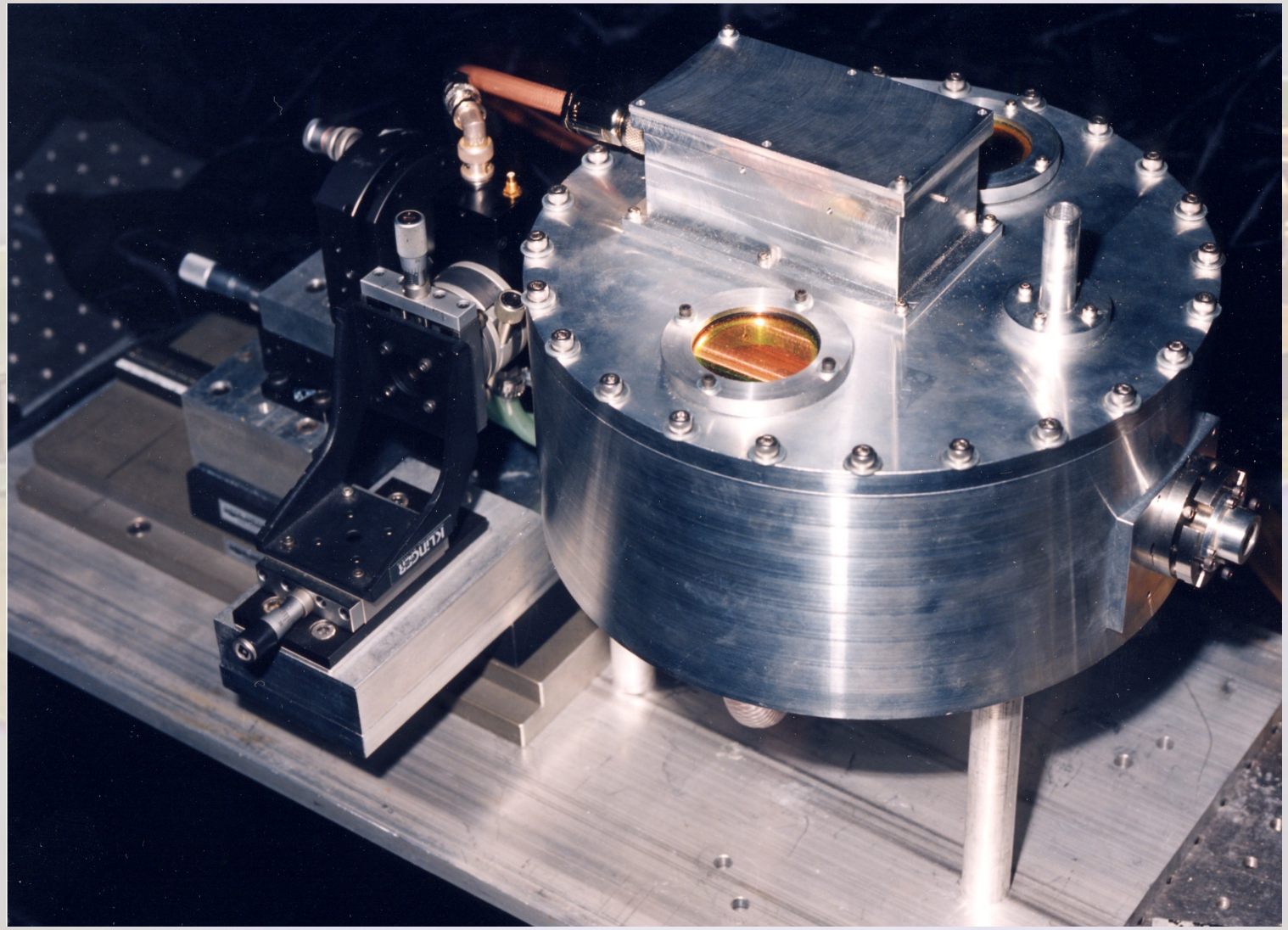
This transmitter maintains coherence between pulses, and thus the RF processor can coherently integrate these pulses to achieve Doppler resolutions orders of magnitude greater than what the limit would be due to a single mode-locked pulse. Coherence is not maintained between the acquisition records which occur 1/10 of a second apart.

This pulse train waveform appears in the frequency domain as a comb of frequencies (axial modes) separated by 50 MHz centered at the optical frequency of approximately 28.3 THz.

This transmitter may also be operated non-mode-locked (single axial mode) for measurements which are unresolved in range (but still resolved in Doppler). In this case, acquisitions are still typically of 1.024 ms duration. However, unresolved measurements are usually obtained by summing the range gates of range-resolved data. This summing may be done either coherently or incoherently, depending upon the detection statistics which are desired.

The coherent transmitter described above has a corresponding single-axial-mode (single frequency), frequency stabilized, CW laser local oscillator (LO). The center axial mode of the mode-locked transmit oscillator is locked with a 10.6 MHz offset to the LO optical frequency. The frequency locking is achieved by mixing a sample of the transmitter and LO output on a heterodyne reference

AMOR 10.6 µm Laser Transmitter



"Secure the High Ground"

LADAR TRANSMITTER SYSTEM – 1.064 µm

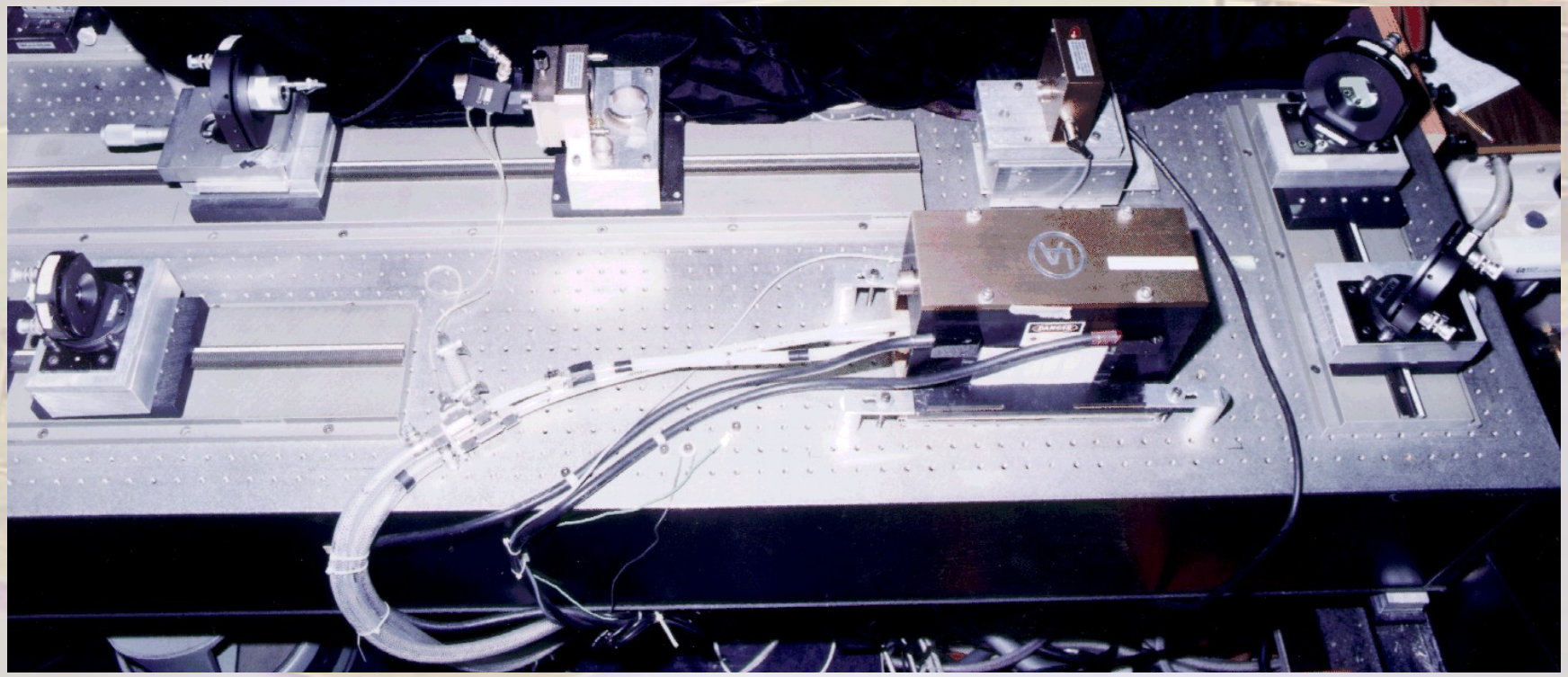
For 1.064 μm range-Doppler resolved measurements, a mode-locked Nd:YAG laser oscillator with a 3-meter resonator is used as the waveform generator. Since it has the same resonator length as the CO_2 MFL laser, it has the same PRF and range ambiguity, but the wider gain line-width of Nd:YAG produces allows a narrower pulse width of 900 ps to be produced.

The oscillator is followed by a pulsed Nd:YAG double-pass amplifier. The amplifier "macro-pulse" width is about 850 μs, and its output thus consists of amplified 850 μs long bursts of 42,500 of the oscillator pulses. The burst energy is 1.2 joule. Coherence is maintained between pulses as was discussed above for the CO_2 system, thus facilitating the achievement of excellent Doppler resolution. The burst repetition rate is 10 Hz. Coherence is not maintained between bursts.

This pulse train waveform appears in the frequency domain as a comb of frequencies (axial modes) separated by 50 MHz centered at the optical frequency of approximately 282 THz. This transmitter oscillator may not be operated single axial mode; it must be mode-locked and used with the range resolving receiver system.

The coherent transmitter described above has a corresponding single-axial-mode (single frequency), frequency stabilized, CW laser local oscillator (LO). The center axial mode of the mode-locked transmit oscillator is locked with a 10.6 MHz offset to the LO optical frequency. The frequency locking is achieved by mixing a sample of the transmitter and LO output on a heterodyne reference detector and using this signal, via a negative feedback control loop, to control the length of the transmitter oscillator via piezoelectric translator. The residual relative frequency jitter, as seen by the heterodyne reference detector, is fed forward to the receiver for frequency correction of the data.

AMOR 1.064 µm Laser Transmitter



LADAR TRANSMITTER SYSTEM – 0.532 µm

For 0.532 µm total cross-section measurements, a Q-switched frequency doubled Nd:YAG laser oscillator is used. It has a 0.532 µm wavelength output of 70 mJ pulse energy, 12 ns pulse width, and 25 Hz PRF. No local oscillator is used; the receiver detector operates as a direct (power) detector.

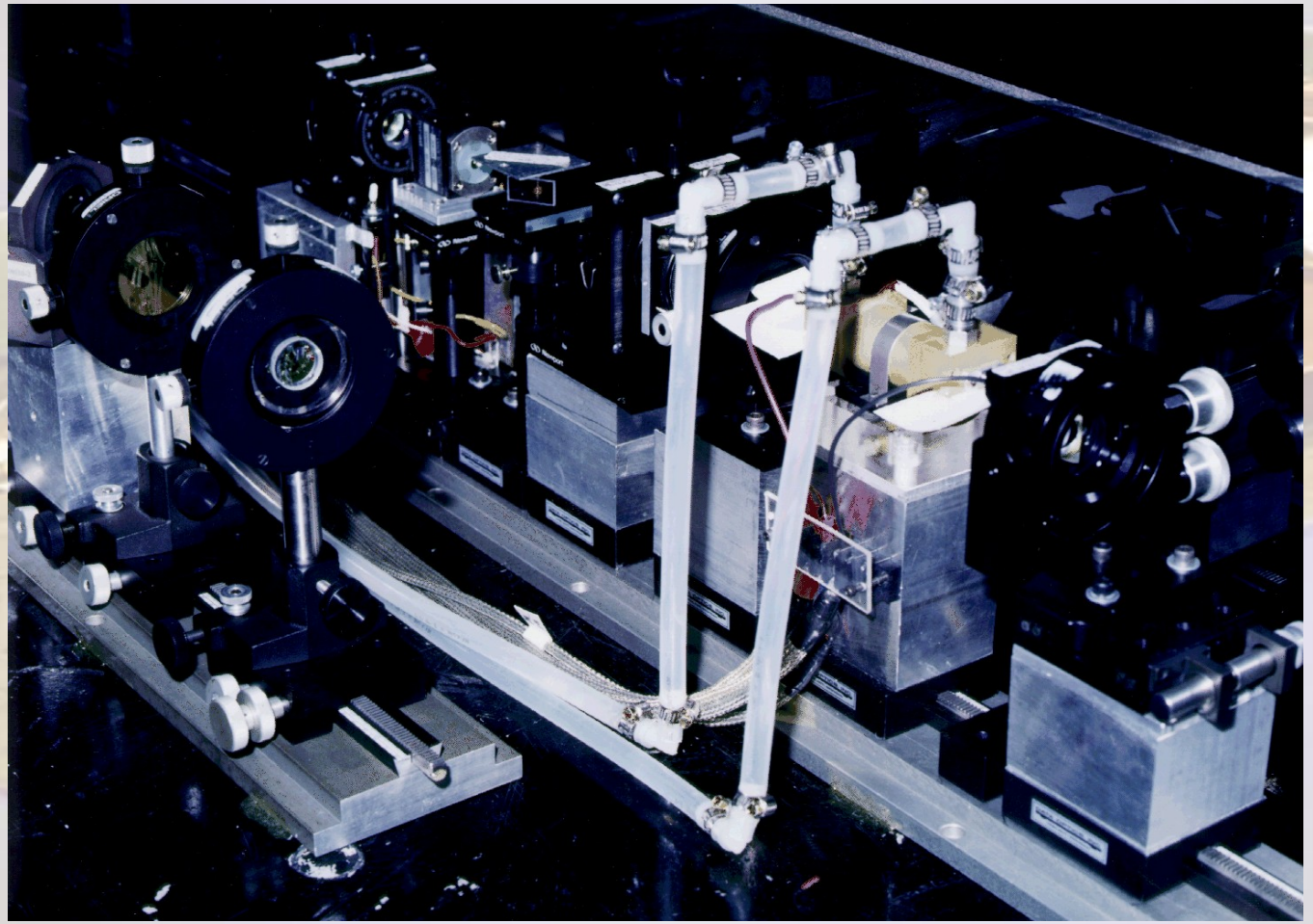
The 1.064 µm Nd:YAG oscillator that feeds the frequency doubler has a 200 mJ, 14 ns, single transverse mode output. It utilizes a crossed-Porro, graded reflectivity unstable resonator with a unique method for thermal birefringence compensation which requires only one laser rod and no Faraday rotator. The residual 1.064 µm light from the oscillator is not separated out or blocked in the transmit path, but an absorbing optical filter is used to block it in the receive path.

The pulse width is not short enough to allow micro-resolution of the target, but it does allow discrimination of the target from the spurious scatter from the primary mirror and from the back shield wall. Only scatter from the target mount shielding remains to be mitigated by data processing techniques.

The electro-optically Q-switched Nd:YAG oscillator has such a fast pulse build-up time that it operates on several hundred incoherently phased axial modes. This results in a coherence length of about 5 mm which repeats at the resonator round-trip length of about 200 cm. About 400 independent sequential speckles per pulse are thus realized for a target with a projected depth of at least 100 cm, each corresponding to a range slice of the target of about 2.5 mm depth. These speckles are exhibited as random signal power fluctuations of about 17 ps duration; since the detector used is too slow to see these fluctuations, it performs the desired speckle averaging, and the detector output pulse appears smooth. This speckle averaging is in addition to the transverse speckle averaging produced by using a multi-speckle virtual receiver aperture.

Targets with projected depth less than 200 cm will produce less speckle averaging; in the extreme case of a flat diffuse plate normal to the transmit beam axis, there would be no axial speckle averaging.

AMOR 0.532 µm Laser Transmitter

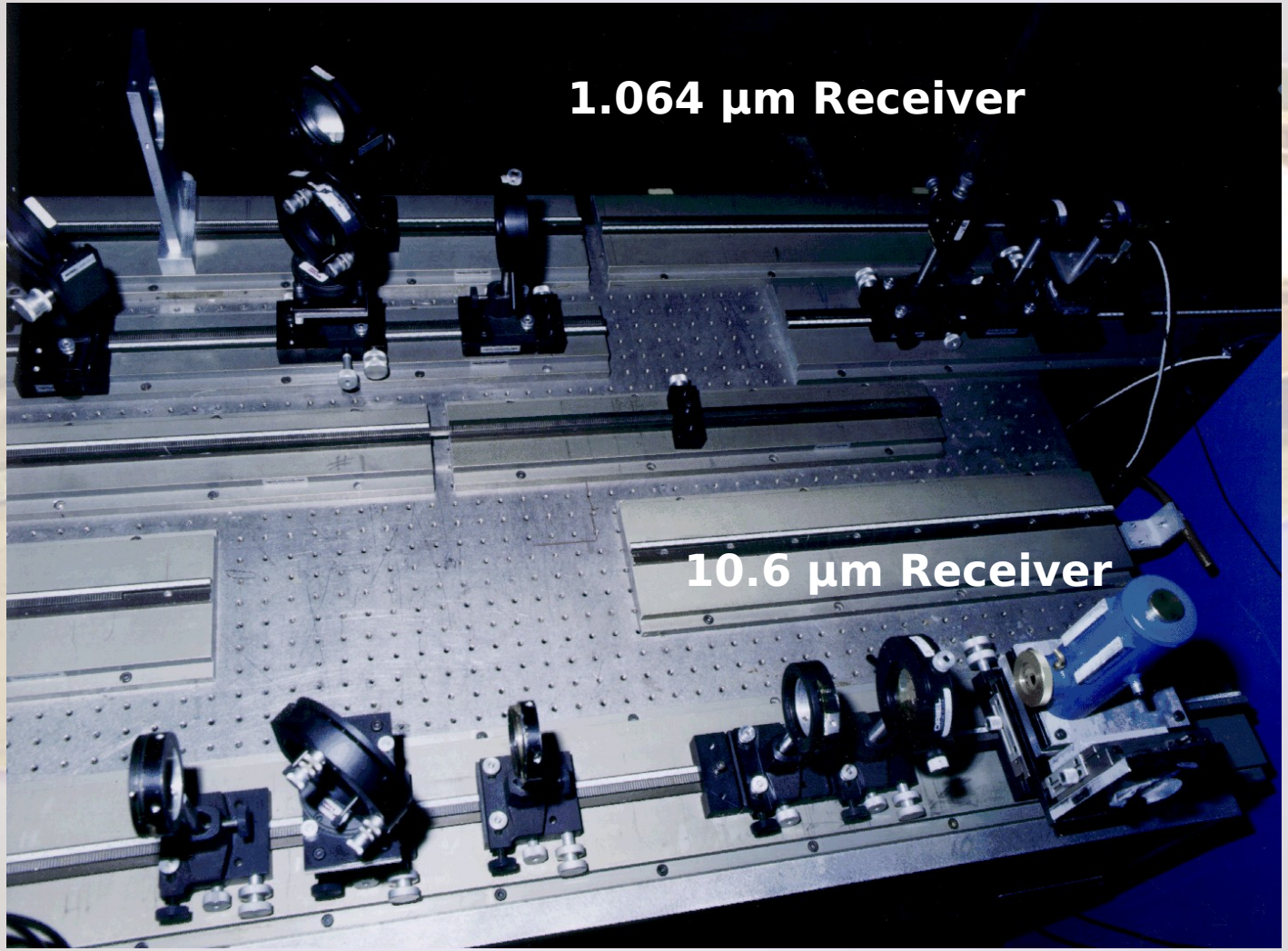


OPTICAL DETECTION AND PROCESSING

For Doppler resolved measurements (10.6 μm or 1.064 μm), the local oscillator output beam is combined with the light received from the target using a beam combiner just before the final receiver focusing lens and pinhole. The LO beam is collimated at the point of combination with the received light, and matched to the target field, so it focuses to a diffraction-limited spot which roughly matches the pinhole diameter. The combined LO-received light beam is then detected by a photodiode. This heterodyne detection allows translation of optical Doppler shift frequencies down to RF frequencies, as well as enhancing detection sensitivity. A high speed HgCdTe photodiode is used for 10.6 μm, and InGaAs is used for 1.064 μm. The detector bandwidth is adequate to reproduce the transmitter pulse width.

For 0.532 μm target measurements, a silicon avalanche photodiode with an integrated trans-impedance amplifier is used in the receive path. After some additional amplification, the detector signal is sent directly to a digital oscilloscope and computer for data acquisition and processing. Off-axis indirectly scattered laser light is rejected by appropriate baffles in the receive path near the detector. Ambient light is not a problem because the acquisition system is looking for 12 ns pulses. Residual unconverted 1.064 μm pulses from the transmitter are blocked by an absorptive glass filter in the receive path.

AMOR Optical Receivers



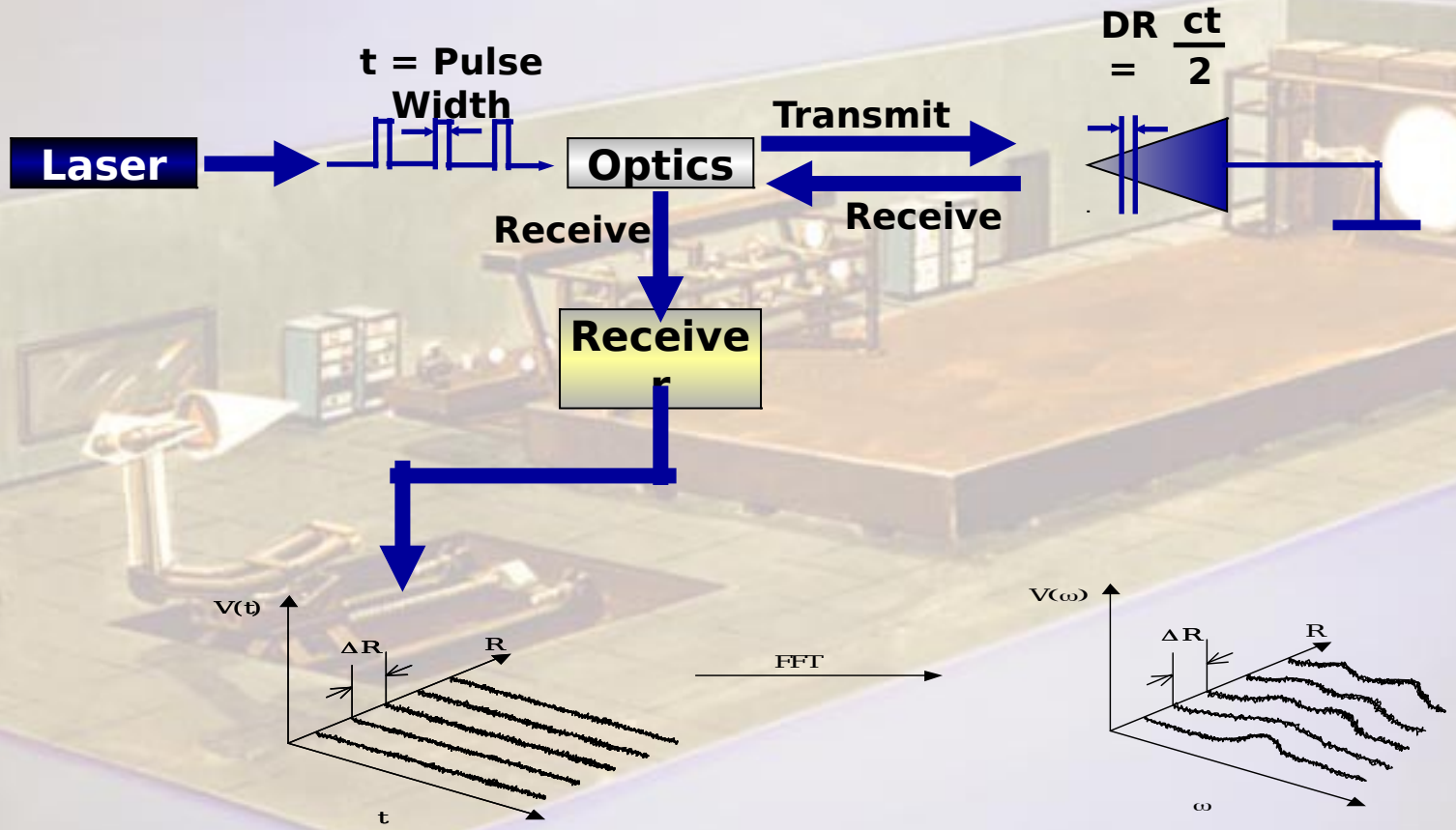
RF SIGNAL PROCESSING

A range-gated coherent RF receiver provides high bandwidth processing to produce a range resolved signal for the coherent (10.6 μm and 1.064 μm) measurements systems. As described below, it also enhances the Doppler frequency stability of the signal and processes the signal in other ways to reduce the burden on the subsequent digitizer and digital processor. The receiver/processor begins by splitting the signal into a set of parallel high-speed time gated channels. The time gates are Gaussian in shape and closely approximate the transmitter pulse shape thus providing a component of matched filtering. For the 10.6 μm system, the gate width is shorter than the transmitter pulse width; this mismatch produces a signal-to-noise loss, but it does squeeze a little better range resolution out of the system. The resulting system power response versus range function is roughly Gaussian. The gates are synchronized with a signal from a transmitter output pulse detector, and the delay to each gate is staggered to provide a gate separation equal to the 50% power width of the Gaussian gate response function. Note that this parallel analog processor eliminates the need to have a digitizer and digital signal processor capable not only of crudely reproducing the laser pulse width (which would require a digitizing rate of a least 2000 MHz), but preferably capable of more precisely matching the Gaussian shape of the analog time gate (thus achieving lower frequency side lobes and lower associated losses), which would require a digitizing rate several times higher. Once the time gating is performed, the separation of the range information is maintained by the containment of the data in separate channels, and high bandwidth and further pulse synchronization and path length control need not be maintained. The signal in each channel is then integrated using band-pass filters, which further reduces the burden on the digitizer and digital signal processor by eliminating the need for it to acquire and coherently integrate pulses arriving at a rate of 50 MHz.

The center frequency of each channel is then shifted from 10.6 MHz down to either 250 kHz or 1 MHz (switchable) to allow even lower digitizing rates in the subsequent data recording stage. This frequency shift process is combined with a feed-forward process from the heterodyne reference detector, which corrects the receive signal by the residual frequency jitter between the transmitter and the local oscillator as measured by the heterodyne reference detector. This greatly enhances the Doppler resolution of the system, and relaxes the frequency locking tolerances between the transmitter and local oscillator.

The RF receiver provides an output of 7 channels, which correspond to 7 range cells. These 7 range cells do not cover the entire range ambiguity and thus may not cover an entire target. To allow

RF Signal Processing



DATA RECORDER AND PROCESSING

For range-Doppler resolved data, the 7 output channels of the range-gated coherent RF receiver are processed by further frequency shifting and anti-aliasing filters, and recorded by a digital acquisition system and signal processor which are hosted by a personal computer. The digitizing per range gate is 500 ks/s. The Doppler bandwidth allowed by the frequency multiplexing scheme is 250 kHz per range channel.

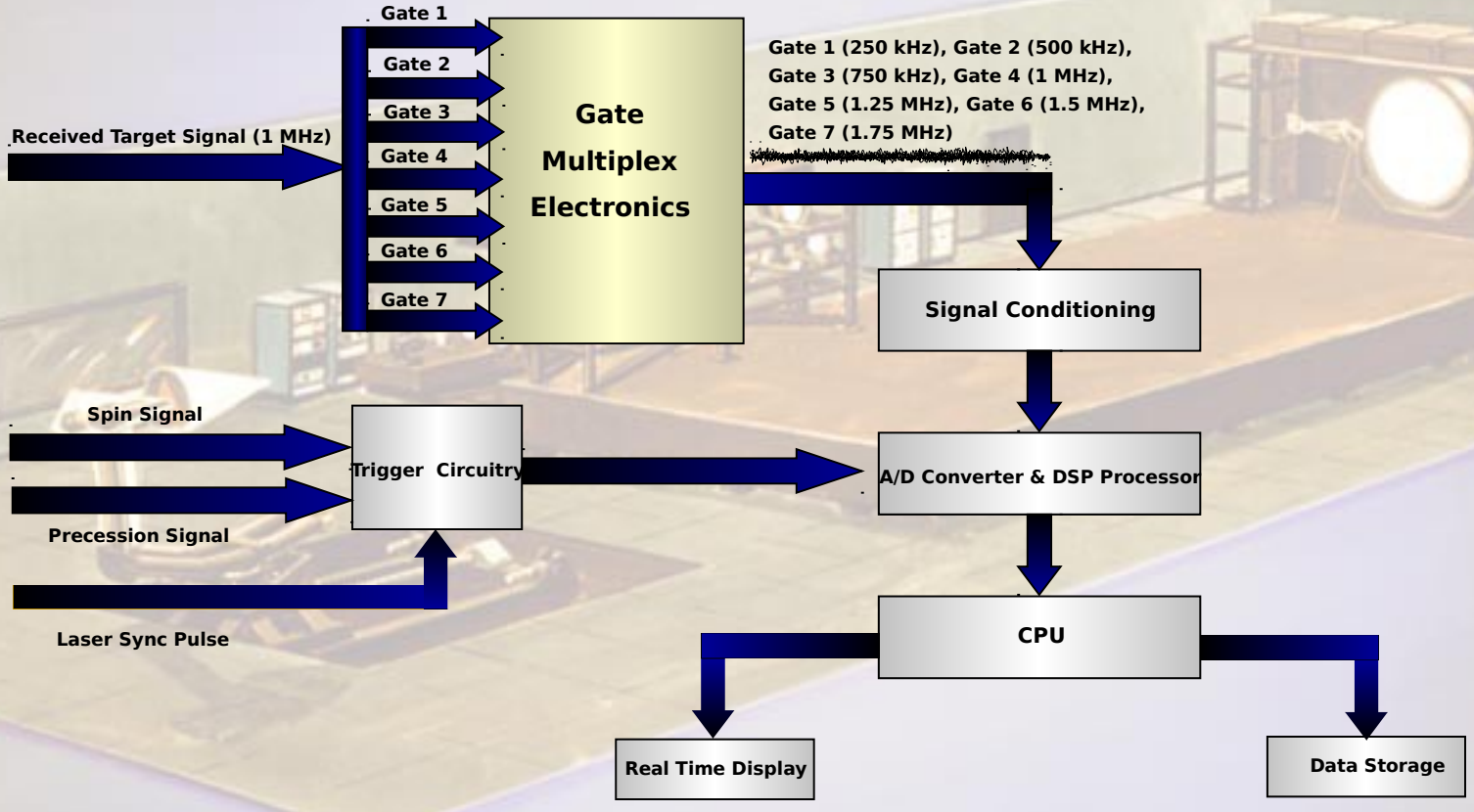
For the 1.064 μm system, synchronization pulses from the transmitter laser amplifier are used to trigger the acquisition of the 850 μs long transmitter bursts, which occur at a rate of 10 Hz. The acquired records are 1.024 ms long. The CO_2 system acquires at a rate of 10 Hz also, though this is triggered by a separate pulse generator, since the CO_2 transmitter produces a continuous pulse train output. Each acquisition record is typically 1.024 ms long for the CO_2 system also, though this may be varied.

The digitized files are then Fourier transformed, which allows range-Doppler images to be produced. The transform length is usually matched to the record length, but it is also possible to perform shorter transforms within each record. The processor allows for incoherent averaging of multiple acquisitions. Total cross-sections and cross-sections per range-Doppler cell are calculated using measured calibration factors as described below.

A real-time display of range-Doppler resolved data is provided by the data acquisition computer to aid in system alignment and to allow the observation and “visual” verification of target data as it is acquired.

For 532 nm total cross-section measurements, the amplified receiver detector output for each 10 ns transmitter pulse is recorded on a digital oscilloscope; each pulse is then transferred to a computer and stored. A pulse detector at the transmitter is used to synchronize the acquisition system; the acquisition record is set to begin after the stray light pulse from the primary mirror is past, and before the back wall shield of the room is seen. After storage on the computer, the pulses may then be averaged, and the total energy in each pulse may be integrated to provide for total cross-section measurements. The pulses are too long to provide for micro-resolution of the target in range.

Data Recorder and Processing



DATA CALIBRATION

Calibration factors are determined (for each range channel in the case of range resolved systems) using specular calibration standards consisting of spherical mirrors of known radius and reflectance. The received signal is recorded for each calibration object, mounted on the target mount one at a time, in the center of each range gate if applicable. This signal level provides a factor relating the receiver output signal to the absolute target cross-section. It is not necessary to measure the absolute received optical power or absolute target irradiance. Several calibration objects of different cross-sections are used to verify system linearity. A full calibration is performed each day that target signature measurements are made. A signal is also acquired with only a stray light shield mounted on the target mount; this serves as a noise baseline and is subtracted from the shot-averaged target data files.

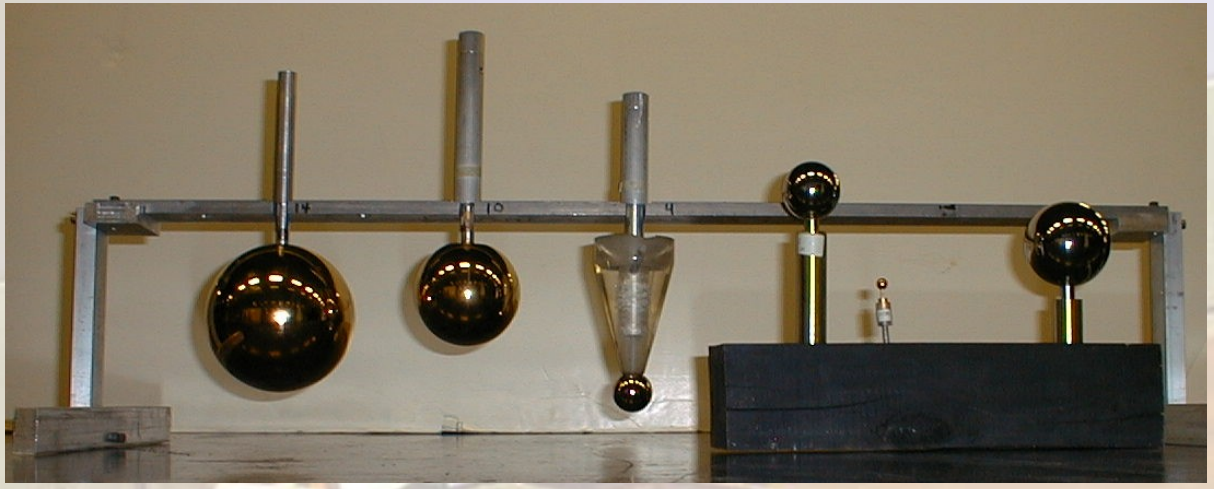
The intersection of the linearity curve with the noise baseline measured above yields the noise equivalent cross-section of the system, and is used as a further verification of the proper operation of the measurements system. The minimum cross-section that can actually be measured depends upon the amount of post-detection averaging and is ultimately limited by spurious scatter from the target mount and other sources in the room.

Target illumination uniformity is verified by scanning a detector across the target plane with the transverse profiling system. The transverse uniformity of the received signal is similarly obtained by scanning an illuminated calibration mirror across the target plane.

The system Doppler resolution is verified by acquiring data from a stationary calibration object and processing the data to show its spectral width. The system range resolution and gate overlap are verified by scanning a calibration object (point source) along the range axis and recording the receiver response for each gate, registered to the changing target mount position.

Collimation of the main transmit and receive telescopes, the laser transmitter output, and the local oscillator beam are periodically verified. Focal plane positioning of the pinhole is periodically verified. A detailed description of these procedures is beyond the scope of this report, but they utilize standard auto-collimation, knife-edge, and shear interferometer techniques. Transverse alignment of

AMOR Calibration Objects



STRAY LIGHT CONTROL AND PROCESSING

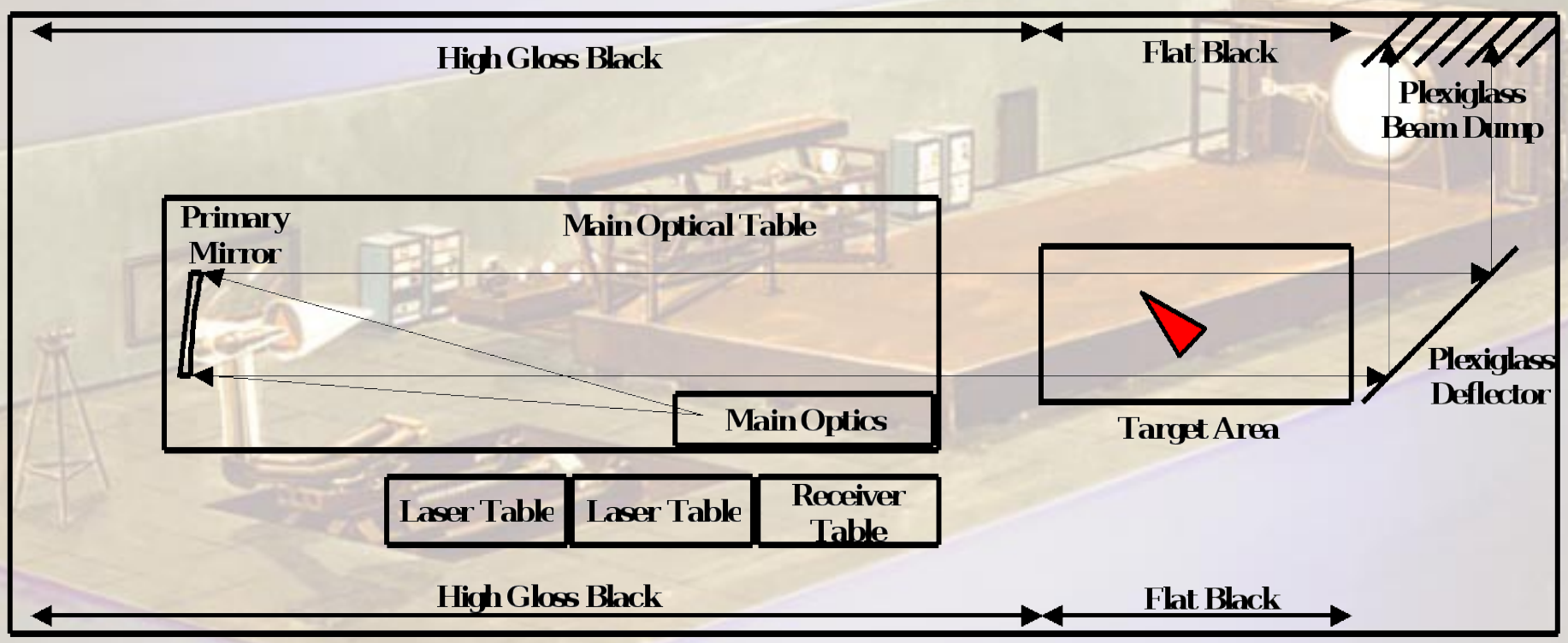
There is some residual diffuse stray light from various stationary clutter objects, including the primary mirror surface, the acrylic light shield backdrop behind the target mount, and the shielding on the target mount itself. The target mask location available in the transmit path allows masking of portions of the target mount and other objects such as unusual target mounting brackets, motors, wires, etc. Using a custom mask at this point can suppress large amounts of spurious scatter in some situations. Most of the remaining stray light is removed with the processing techniques described below.

For the range-Doppler imaging transceivers, the target must be positioned out of the range ambiguity that contains the scatter from the primary mirror. A slight amount of primary mirror scatter signal bleeds through into other range gates, and there is also a small contribution from the back shield and from the target mount itself. These sources are stationary and their signal has no Doppler shift. The signal from this stationary clutter thus appears in a single Doppler cell, and may be interpolated over when the target is spinning, which produces a target signal Doppler spread. This cannot be done for 0˚ aspect angle, since there is no Doppler spread in this case and all of the target signal will be at 0 Hz.

If the target has an extremely small ladar cross-section, it cannot be spun rapidly or the signal will spread out so that the signal per Doppler cell falls below the minimum detectable cross-section. If the spin rate must be reduced to the point that it produces only a few Doppler cells of signal width, interpolating over the stationary stray light could remove too large a fraction of the signal. Also, when looking at extremely low signal levels, the contributions of the stationary stray light to Doppler cells adjacent to 0 Hz could be significant in comparison to the signal. In this case, the data may need to be acquired with the target in motion along the range axis. This provides a Doppler shift which allows the target signal to be distinguished from that of the stationary clutter. A gate tracking system is available which allows the gate delay to exactly track the target mount axial position. The target will then remain fixed with respect to the range gates as it is translated to produce Doppler shift.

For the incoherent, 532 nm measurements system, stray light may not be separated in the frequency domain. However, since there is no range ambiguity, and the range resolution is about

Stray Light Control and Processing



SYSTEM ACCURACY AND MAXIMUM TARGET SIZE

For the coherent systems (1.064 μm and 10.6 μm), the cross-section measurements accuracy is limited by the round-trip transverse system response varying by about ±12.5% to ±25%, depending upon the beam expansion and pinhole used. Part of this variation is due to the transmit beam intensity roll-off from the beam center to the edge; the remainder is due to the receive path transverse response roll-off. The only way to make the transmit profile flatter would be to further expand the beam expander input beam, thereby reducing the total power within the 2-meter field. The only way to flatten the receive profile would be to use a smaller pinhole for the virtual receive aperture, and thereby reduce the signal level.

For the incoherent system (0.532 μm), the transmit beam profile roll-off is about the same as that for the coherent systems. The receive profile is much flatter, since it is not limited by heterodyne phase matching. The net effect is about ±12% round-trip variation across the field. Measurements made on targets which fill only the central portion of the 2-m measurement system field will have a better accuracy because of the flatter response uniformity in this region.

Due to the 1.064 μm and 10.6 μm transceiver waveform's range ambiguity, targets longer than 3 meters cannot be measured at nose-on aspect at these wavelengths. At 33.5° aspect angle, a 3.6 meter long target can be measured, but at greater then 33.5°, the allowed length decreases again due to the 2 meter wide primary mirror. Longer targets may be measured a portion at a time, however. A portion may be allowed to hang outside of the 2 meter transverse field, thus measuring only the portion within the field, or a portion of the projected range dimension may be measured by masking or shielding the remainder of the target.

The 532 nm total cross-section measurement system has no range ambiguity, so there is no limit to target length that can be viewed at a nose-on aspect angle. However, at other angles, there is still the 2 meter diameter field limitation.

TYPICAL DATA ACQUIRED

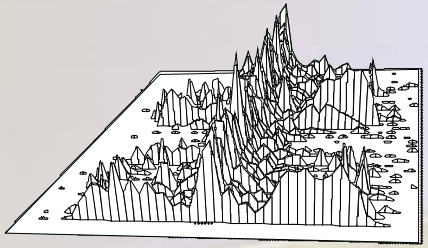
Target data are typically acquired for VV, HH, VH, and HV polarizations at 0, 15, 30, 45, 60, 75, 90°, and broadside. The transmit path is normally used to flood illuminate the target with a collimated beam, and the receiver is usually configured to produce a virtual aperture at infinity. Range-Doppler measurements are made with a speckle matched virtual aperture, and direct detections measurements are usually made with a multiple speckle aperture.

For coherent measurements, targets are typically spun to produce about 50 kHz of Doppler spread. If the signal is extremely low, a lower spin rate is used. Even for low signals, enough spin rate is always used to allow for independent speckle realizations for each acquisition. If possible, the spin rate is set to collect data over a full rotation to allow for averaging of possible rotational asymmetries.

Five hundred and twelve laser shots are typically acquired. Extremely low cross-section targets may require more shots. More shots may be required if it is desired to register data to rotational or precessional orientation, or to allow averaging over a full rotation if a low spin rate is required. All shots are typically averaged together to improve signal-to-noise and to average over multiple speckles.

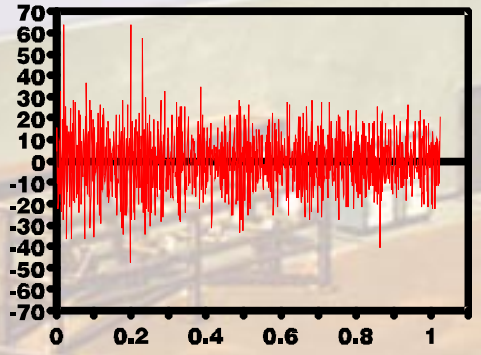
Calibrated graphs of range-Doppler resolved cross-section, range-resolved cross-section, and total cross-section are typically presented for each angle measured. For the unresolved measurements system, only the total cross-section can be obtained. Raw data files of the individual laser shot acquisitions are available to allow data users to analyze speckle statistics or to process or present the data by alternate methods.

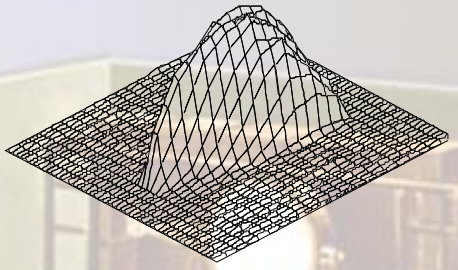
Typical AMOR Data



Doppler-Time Image

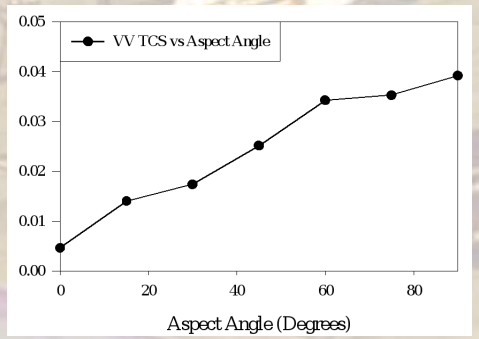
Voltage vs. Time



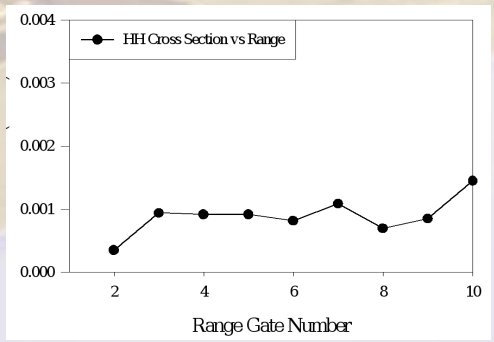


Range-Doppler Image

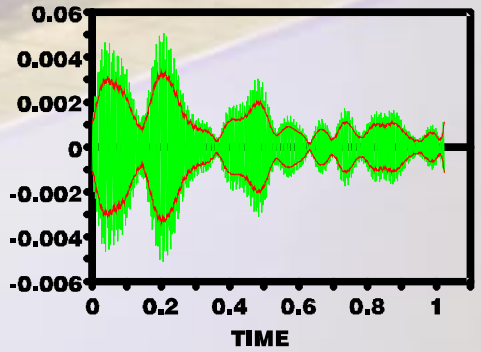
Cross Section vs. Aspect Angle



Cross-Section vs. Range



Speckle



SUMMARY

AMOR is a multifunctional facility capable of supporting several missile defense mission areas.

Target Measurements – AMOR provides the capability for ladar measurements on a wide variety of RVs, decoys, tactical and analytical targets. A history involving many target measurements ensures fully characterized measurements of new targets.

Ladar Sensor Testbed – AMOR is an excellent ladar sensor testbed, from the visible regime to the long-wavelength infrared one. Critical functions of a ladar sensor can be tested using the engagement conditions that are simulated at AMOR.

Algorithm Development and Testing – Calibrated range-Doppler images, range-resolved target cross-sections, and total cross-sections on realistic targets undergoing spin and precession motion provide essential data input for validation of laser radar cross-section calculations and for discrimination algorithm development and testing.

Advanced Ladar/Passive Sensor Concept Development – AMOR is a unique testbed for developing ladar/passive sensor concepts utilizing the simultaneous ladar/passive measurement capability at AMOR.